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The Aerovox Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on capacitors and resistances for radio work.

VOL. 18, NO. 10 OCTOBER, 1946

50c per year in U.S.A.
60c per year in Canada

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PART 8. THE CRYSTAL DIODE

By the Engineering Department, Aerovox Corporation

For some time past, the word *crystal* appearing in technical articles has been assumed to refer to quartz crystals or plates used to stabilize r. f. oscillators; to modify the selectivity characteristics of intermediate frequency amplifiers, or to sustain supersonic oscillations. The terms *oscillating crystal* and *resonator crystal* were abandoned sometime ago in favor of the single word. Now, the picture has been altered by the reappearance upon the radio scene of the rectifying crystal. It is convenient to refer to the latter as a *crystal diode*.

The crystal rectifier is far from being a new electronic circuit component. It was employed widely as a simple detector in tubeless radio receivers twenty-five years ago. In its early form, the crystal detector consisted of a lump of some mineral (technically a "near-metal"), such as galena, silicon, iron or copper pyrites, zincite, bornite, or carborundum connected to one side of the circuit, and a feeler wire termed the "catwhisker." In most cases, the catwhisker was a fine wire, and its contact with the crystal surface very light.

Operation of the device as a rectifier is based upon its nearly unilateral conductivity — currents pass many times more readily in one direction (e. g., from catwhisker to crystal) than in the opposite direction. The chief disadvantage of this type of rectifier is the fact that not all portions of the mineral rectify equally well. Instead, "sensitive spots" must be searched out on the crystal surface with the catwhisker. These spots are destroyed easily by overload and heat, and are lost by unintended movement of the catwhisker. The early appeal of the crystal rectifier was due to its simplicity as a two-terminal device, its low cost, and the fact that it required no battery except in the case of the carborundum crystal. However, the early crystal detector was neither as sensitive nor as table as its vacuum-tube equivalent, nor was it as convenient to operate.

Crystal detectors fell into disuse because of their low sensitivity, electrical and mechanical instability, and need of almost continual readjustment, and due to the important fact that vacuum tubes, which require no comparable adjustments and exhibit no such instability, became cheap enough to warrant their widespread use. Sparse instances of crystal detector application in special receivers and test instruments were recorded as late as the early thirties. But even these cases disappeared when small, low-capacitance diode tubes became available. Admittedly, a few simple, short-range crystal broadcast receivers, of the early style, are manufac-

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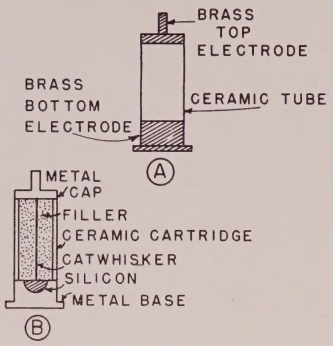

FIG. 1

tured and sold today, but these items satisfy a toy appeal more than they seriously compete with power-operated tube receivers.

The crystal rectifier assumed new importance in ultra-high- and super-high-frequency circuits developed during World War II because of certain other desirable characteristics possessed by this device. Noteworthy among such characteristics are low capacitance, freedom from the transit time effects which render conventional tubes inefficient or inoperative at the extremely high frequencies, small physical size compared to the diode tube, and the fact that the crystal rectifier requires no local power supply for its operation. At radar frequencies counted in thousands of megacycles, where period is a small fraction of cathode-grid or cathode-anode transit time, specialized stabilized *crystal diodes* have found use as detectors, mixers, and meter rectifiers.

Most crystal diodes employed in microwave equipment differ from the early mineral detectors, however, in the following important respects. They are efficiently fixed (i. e., the catwhisker has been set rigidly in contact with a sensitive spot in the initial adjustment at the factory, and literally locked in that position); they are mechanicaly and electrically more stable than their predecessors, and they are capable of withstanding a higher momentary overload without destruction or alteration of their characteristics (although the modern crystal rectifiers still can be burned out by strong radio-frequency fields). The new crystal diodes are considerably smaller in size than the early mineral detectors.

STRUCTURAL FEATURES

At this writing, the new crystal diodes are supplied in two styles, illustrated by Figures 1 and 2. The type shown at 1-A has been shaped for easy insertion and plugging into specially designed cavity resonators and coaxial butterfly circuits. Its design also makes this type usable as a signal pickup probe in wave guides and cavities. Overall length of this type is approximately 13/16 inch, and its maximum diameter is approximately 5/16 inch. Similar construction is found in Types 1N21B, 1N22, 1N23B, 1N25, 1N26, 1N31, and 1N32.

The crystal diode shown at Figure 2-A has a construction resembling that of a fixed resistor, and is about the same size as a small 1-watt resistor. Pigtail leads on this diode permit soldering it directly into circuits where close mounting, short leads, and the self-supporting feature are desirable. In fact, it may be installed in a circuit as easily and in the

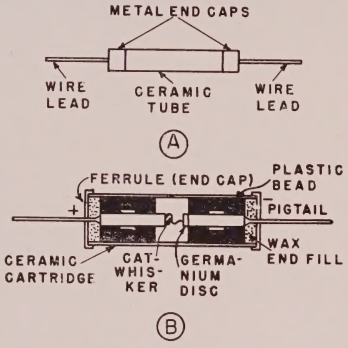

FIG. 2

same manner as a conventional resistor. The approximate overall length of this type, excluding lead lengths, is 3/4 inch; the maximum diameter approximately 7/32 inch. The design is characteristic of Type 1N34.

Silicon is the sensitive material employed in the type of diode shown in Figure 1-A. Whereas a thin disc of optically polished germanium, soldered to the end of a wire, is used in the type shown in Figure 2-A. In the first type, a suitable filler material, generally plastic, is flowed into the ceramic cartridge after adjustment of the catwhisker. This material serves to secure the setting. In the second type, (Figure 2-B), a spring-type tungsten catwhisker with sharp point is in contact with the highly polished germanium disc.

Silicon type diodes (Figures 1-A and 1-B) are designed for frequencies from 1000 to 25,000 megacycles, depending upon type number. Type 1N34 germanium diode has been recommended for use between 0 and 100 megacycles, although operation has been recorded as high as 500 Mc. The silicon group was designed especially for use in the first detector stages of super-high-frequency superheterodyne receivers, and for tuned r. f. and video detector use at super high frequencies. The germanium type was designed expressly for superheterodyne second detector applications, but finds use elsewhere too, as in FM and television reception, where load resistance values are low.

OPERATION

This paper wil not enter into the complex physics of crystal rectification. The plot of Figure 3 serves to illustrate the front-to-back conduction which is characteristic of all crystal rectifiers. From this curve, it may be seen that small positive voltages impressed upon the crystal diode cause rather large values of current to flow through the circuit, while much larger *negative* voltages cause considerably less current flow. Thus, there is always some current flow in the reverse direction through the comparatively high back resistance, and the crystal diode is not a perfect rectifier. However, this current is so small as to be negligible in usual operation.

It is interesting to note that the maximum peak inverse anode voltage for Type 1N34 is 50 volts, and the maximum peak sine-wave anode current, 60 milliamperes. The back conduction at 50 volts is only 2 milliamperes, while the maximum average anode current is 22.5 milliamperes. Maximum recommended surge current is 200 milliamperes.

APPLICATIONS

The usual characteristics of the crystal diode — its low capacitance, high self-resonant frequency, small physi-

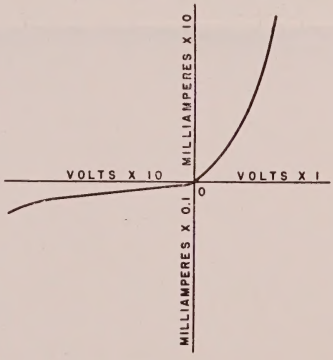

FIG. 3

cal size, freedom from transit time effects, independence of local power supplies, and freedom from emission current — recommend it for various applications at radio frequencies, particularly the extremely high frequencies. Several skeleton circuits and functional block diagrams in Figure 4 illustrate some of the common applications.

A v. h. f. wavemeter of the absorption type is shown in Figure 4-A. The variable capacitor shown has dual stators and a common rotor, eliminating wiping contacts. In v. h. f. circuits, the simple L-C circuit is often replaced by a butterfly tuning arrangement.

Figure 4-B shows a v. h. f. wavemeter of the transmission type. In this instance, the unknown signal is delivered to a cavity resonator through a coaxial line. The crystal diode and meter likewise are coupled to the cavity by means of a coaxial line. Resonance occurs when the unknown frequency coincides with that of the cavity, or vice versa, as indicated by maximum deflection of the indicating meter. In a somewhat similar circuit (the absorption- or reaction- type of cavity wavemeter), the unknown signal is delivered to the cavity through the same line employed to couple the crystal diode and meter. Operation is identical with that of the transmission-type wavemeter explained previously.

Figure 4-C is a simple half-wave second detector employing a crystal diode. Figure 4-D is a crystal-diode frequency discriminator circuit for FM. Figures 4-E and 4-F are simple rectifier-type meter circuits employing crystal diodes. 4-E is the half-wave version, while 4-F is the bridge circuit. Both arrangements are useful on low-frequency a. f. as well as r. f. circuits.

Figure 4-G shows the arrangement of a heterodyne-type v. h. f. frequency meter. An arrangement such as this is employed in the General Radio Type 720-A Heterodyne Frequency Meter. The latter instrument uses a butterfly-type oscillator having a tuning range of 100 to 200 megacycles to give the complete instrument a range of 10 to 3000 megacycles.

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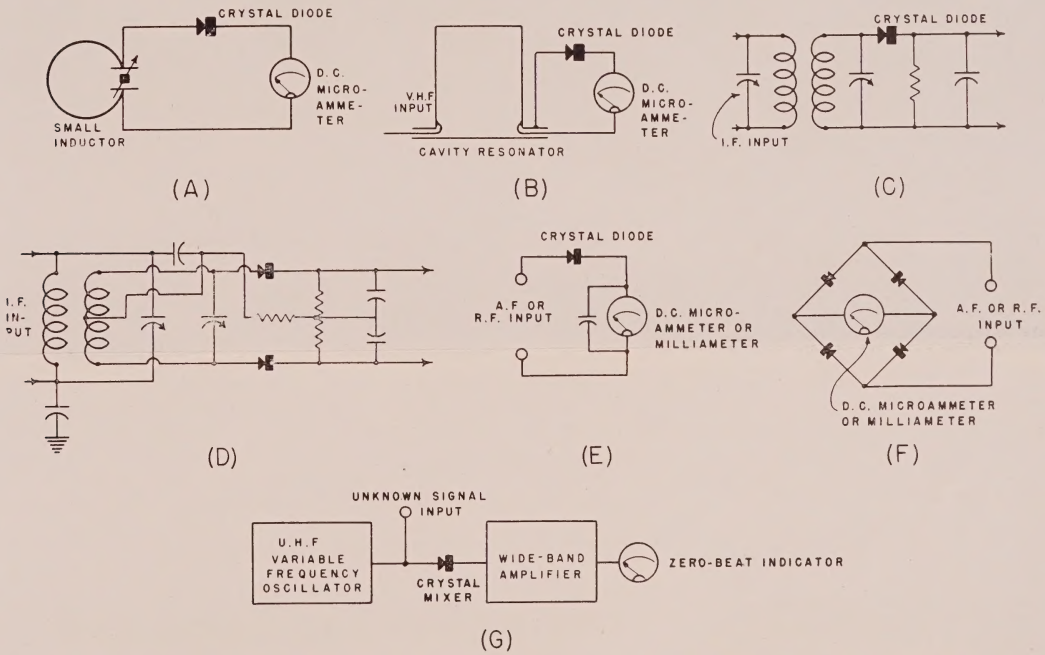

FIG. 4

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